Making hard-rock history

The newest concept in mining? Think again. Hard-rock cutting has a long and winding past, reports Carly Leonida

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The prototype of Joy Global’s DynaCut machine, which is believed to be preparing to start trials at a mine site

Which concepts or technologies would be top of your ‘to watch’ list for mining? I’d put bets on hard-rock cutting being up there. But you’d be mistaken in thinking this is a ‘new’ development. In fact, it’s anything but.

Mining companies and OEMs alike have been working on the concept since the 1980s.

“The idea of hard-rock cutting goes back more than 30 years,” explains Uwe Restner, product line and sales support manager at Sandvik. “Basically, the idea of hard-rock cutting developed with the success of mechanical cutting and mechanisation in coal and soft rock; the hard-rock miners also wanted to have what the soft-rock miners had.”
Jens Steinberg, head of new product introduction and business management for Caterpillar’s hard-rock cutting line, concurs: “It has been a vision of the company for more than 15 years to make continuous mining available for the hard-rock mining industry,” he tells MM.

“In coal and soft-rock mining, longwalls and continuous miners have set safety and performance standards. Hard-rock cutting technology is the key to make such safety and performance standards also available for hard-rock mining customers.”

**SA in the driving seat**
Back then, Caterpillar’s hard-rock cutting product development team was part of underground-mining specialist DBT, which was later purchased by Bucyrus and then Caterpillar in 2011.

“Since the early phase of the development, one of the South African platinum-mining companies has been very interested in the common development of hard-rock cutting technology,” explains Steinberg.

“The objective [of early tests] was to evaluate if hard-rock cutting was possible, and if continuous mining of hard rock could be realised.

“Generally, this technology was requested by the industry towards the end of the 20th century. However, initially this technology fell short of expectations, which led to some disappointment and scepticism.”
The Cat Rock Straight system features a number of cutting heads equipped with picks. The cutting units can be staggered to accommodate different seam heights.

Although Caterpillar has dominated the headlines of late with the launch of its innovative Rock Straight longwall-style system for hard-rock mines, it was by no means first to market with a hard-rock mining machine.

Sandvik’s journey also began in South Africa, with one particular miner championing a series of innovative cutting tests underground.

“The real journey began mid-nineties when we were looking for a so called ‘flat-end development concept’, “ says Restner.

“At this time, we still produced tunnel boring machines (TBMs), applying conventional disc cutting technology. This early ideation process finally resulted in contractual R&D work in co-operation with Lonmin, and the result was the ARM 1100 (Alpine Reef Miner) with 1,100mm cutting height, which is now called the MN220. The MN220 is still the most successful innovation applying disc-undercutting technology at commercial scale in platinum production.”

This was followed by a further co-operation with Lonmin for the development of a machine capable of driving boxholes. The first reef miner came to the market in 2001, and the ABH 1600 (Alpine Boxhole Borer) with a boring diameter of 1,600mm (now called the MD320) was hot on its heels in 2004.

“Both the machines worked quite well, but unfortunately the mechanisation process in platinum mining did not really continue,” adds Restner.

Around the same time, fellow OEM Joy Global became involved in hard-rock continuous mining, through discussions with Platech (a consortium of major platinum producers in South Africa, including Anglo American), and independent research institute CRC Mining in Australia.

Brad Neilson, president of hard-rock mining for Joy Global, tells MM: “Joy completed a thorough assessment of various cutting technologies, and a decision was made to pursue the Oscillating Disc Cutter (ODC) technology. The ODC technology at that point had been in a research phase for approximately 10 years.”
Members of Platech were actively seeking this type of advancement, and encouraged Joy to become involved. “Hard-rock continuous mining was seen as the ‘Holy Grail’ to selectively mine more safely, more productively and at a lower cost,” says Neilson.

“For many years, Platech members have been champions and supporters through a difficult process of taking a research-scale concept to a viable alternative to drill-and-blast mining methods. So, support from the industry has been strong.”

For Sandvik, the call to arms came again in 2008 when Rio Tinto announced its Future of Mining programme and the need for a rapid mine development system (RMDS). Rio evaluated several different concepts and eventually developed prototypes with Atlas Copco, Herrenknecht and Aker Wirth.

“In 2008 we picked it up again, when Rio Tinto was calling for a tunnel-boring system,” says Restner. “From this time, we continued working on the RMDS topic and, in the first half of 2015, we came to the final conclusion which way to go with our concept.

“In parallel, we also developed and built a new high-load rock cutting test rig for exploring different types of hard-rock cutting technologies.

“Of course, finding the right hard-rock cutting technology was also one of the triggers for the R&D process. The task was to find a smart hard-rock cutting technology enabling us to create a smart machine concept with the right flexibility, mobility and manoeuvrability for underground hard-rock mining applications.”

Rio’s Future of Mining programme also sparked a renewed interest in hard-rock cutting for Atlas Copco. The company has been working on hard-rock tunnelling concepts since the 1960s, and began work on its latest generation of machines aimed specifically at the mining industry in 2009.

“The new generation of machines started with a request and project from Rio Tinto for their large block-cave mines,” says Mikael Ramström, manager for global strategic projects and alliances.
“Rio Tinto wanted a new innovative solution for rapid mine development instead of drill and blast. The requirement was to achieve 12m/day of continuous tunnel development; comparable data on drill and blast was 4-6m/day.”

Following the success of Atlas Copco and Rio Tinto’s Mobile Miner, which uses steel disc cutters borrowed from traditional TBM designs, Anglo American also approached the company (Anglo is backing the development of four different hard-rock cutting systems in total, including Joy Global’s Dynacut and Atlas Copco’s rapid mine-development system.)

Design work began in 2012, and Ramström says the final touches were added last year.

“We were not far off with our first RMDS design, and together with Anglo American we have made improvements to meet the specific mine requirements,” he adds.

**Powering through the downturn**

While programmes such as Mine of the Future may have kick-started development of the latest-generation hard-rock miners, there is no doubt that the industry downturn of 2008-09 hit OEMs and mining companies hard. While the need, and desire, to take these concepts forward was present, cuts to R&D spend meant that it was nearly four years – 2012 – before trials seriously began.

During that period, costs increased and mass-mining methods became ever more important to the future of mining, driving the need for increased rates of development at a lower cost. “Hard-rock continuous mining was seen as a potential solution to this problem, so the interest grew,” says Neilson.

Steinberg adds: “The technologies did not make the breakthrough, and funding ceased in the cyclical downturn of the mining industry. It took until 2011-12 during the last boom for the mining industry to make funding available again for R&D in the field of hard-rock cutting. The goal was to accelerate mine development and to find ways to extract ore more productively and more selectively.”

Restner says: “Just imagine what it will mean to the NPV of an ore deposit, when you could speed up mine development and get access to your ore two, three or even four times faster. Underground infrastructure development speed is the real driver for mechanical hard-rock cutting.”
Ramström agrees: “I think that the Mine of the Future project made the mining industry aware of what could be possible. It is a shame that the downturn in the mining industry punished Rio Tinto so hard for that initiative. We need actors in the industry thinking big and with perseverance who are prepared to take the next step and not only make continuous improvements.”

**Activated undercutting**

Today, Caterpillar’s underground hard-rock line consists of three products: the Rock Flow system, a continuous haulage system for block-cave mines; Rock Straight, a longwall-style cutting system that was launched in June; and Rock Header, a road header also for hard-rock mines.

The company’s very first cutting units applied complex gearing to achieve movement of the cutting tools as a result of the interaction of rotation and oscillation.

“The mechanical complexity has since been significantly reduced and the cutting efficiency further improved,” says Steinberg.

Since the beginning, Caterpillar’s formula has been the combination of undercutting rock in combination with activated cutting tools. The concept has been refined in many aspects but still follows the same formula.

The undercutting method works by attacking the rock’s tensile strength rather than its compressive strength, meaning the forces required to break the rock are much lower. Caterpillar’s Activated Undercutting Technology further improves the cutting process by ‘activation of the cutting tools’. The cutting units used on the Rock Straight system and the Rock Header feature a number of cutting heads equipped with picks. These rotate off-centre to the drum axis and, as they swivel, the pick briefly hits the rock. The percussive effect generated causes the rock chip to break. This short period of contact reduces the amount of heat generated, resulting in less pick wear, lower energy consumption and lower stress, enabling the excavation of hard rock using a small, compact machine.

“The undercutting effect leads to reduced cutting force requirement, while the activation, the application of momentum to break rock, leads to low pick wear and low resulting forces and allows the cutting machines to be light and mobile,” Steinberg tells *MM.*
The very first generation of activated undercutting machines still used discs as cutting tools. “They did cut very effectively over a short period of time until the cutting edge of the disc became blunt and then, as a result, the cutting forces increased exponentially and required large efforts in terms of bearing of the disc shaft,” Steinberg adds.

“That is why the application of discs has been dismissed and shank bits have been used since. They maintain a constant tip angle while wearing and cutting forces do not reach critical limits.”

It took years and various evolutionary steps until the current performance level and reliability of the activated undercutting technology was reached.

The Cat Rock Straight system is the first new-generation hard-rock cutting machine to be made commercially available. It comprises three key elements: cutting, haulage and roof support, all supported by automation.

MM was one of the first to see the new machine at Caterpillar’s German training facility in April and full details of the machine can be found here.

“In the case of the Cat Rock Straight system, it was also necessary to develop all other components for the conditions of hard-rock mining. The handling of abrasive ore for instance puts high requirements on the design of the face conveyor to keep wear and cost down,” says Steinberg.

“While many tests of the cutting technology can be made on a cutting test stand, it requires a mining section to validate a complete mining system. The validation of an entire hard-rock longwall is not a walk in the park and it requires a long-term co-operation between an OEM and a mine to complete the validation.”

In this case, Caterpillar teamed up with Polish copper miner KGHM and tests, which began 4-5 years ago, continue today. According to Steinberg, the companies “shared the vision of the benefits of hard-rock cutting in the extraction of seam-type deposits, and joined forces to refine the development and validation of the Rock Straight system”.

Rock Straight is primarily designed for the extraction of flat, tabular deposits and reefs of gold, copper, PGEs and chromite.
“The volume of platinum, chrome, gold and copper mined from low reefs and low seams in southern Africa, Europe and the CIS is very significant,” Steinberg tells MM. “In addition to these deposits, there are other potential applications such as the dome-type deposits that typically have rather horizontal sections.”

The application of Rock Straight provides advantages such as selective high-performance mining in such deposits. The system offers increased extraction rates, and faster development of the drifts is required as a result.

“Here, but also in almost any other underground mine, faster mine development provides big customer advantages such as earlier access to new deposits, increased production rate in existing mines as new mining stopes can be exploited earlier, and an earlier start for underground exploration drilling,” Steinberg explains.

Other Caterpillar product developments such as Rock Header are therefore focused on the application of Activated Undercutting Technology in continuous high-speed mine development.

“This year’s Massmin conference in Sydney was an ideal opportunity to engage with the block-caving community and to trigger a thought process around the application of continuous mining in block and panel caving,” Steinberg says.

“The Cat Rock Flow system is already available for continuous haulage of ore in block and panel cave mines to achieve higher production rates.

“The Rock Straight system could be used to develop the undercut level in block and panel caving mines and allow higher development rates and more efficient caving as a complete undercut is always guaranteed.”

**Oscillating disc cutting**
For Joy Global, the first step toward development of a new-generation hard-rock cutting machine was a full-scale surface test rig in South Africa, to prove that its Oscillating Disc Cutter technology could work cutting platinum.

Once that was established, it was on to step two, a proof-of-concept mining system that went underground in November 2010 to operate in a platinum reef.
“Step three was the introduction of an improved version of the cutting technology on the underground machine (named the HRCM10, Hard Rock Continuous Miner), which has a 1.0m cutting height,” explains Neilson. “Step four was a full-scale concept review in 2012, based on the two years of experience underground with a complete continuous mining system.”

Step five was the development of a new Joy cutting technology called DynaCut based on a deeper understanding of the fundamentals of the cutting technology. And finally, step six was to develop and build a full-scale prototype machine to continue surface and underground testing, “which is where we are now”, according to Neilson.

Through continued advancement, Joy has improved its cutting rates by more than ten times in just two years. “Energy in, and cut rock out, has improved dramatically – meaning a smaller, lower-mass, lower-cost mining machine. Machine size and mobility is important. The underground mining process requires fast mobilisation, and flexibility to cut turns,” adds Neilson.

“We have been focused on Oscillating Disc Cutter technology since that initial assessment of options, and are working toward commercialisation. DynaCut technology is now in a pre-commercial phase.”

Joy has had a number of significant technical barriers to overcome, including: material handling, life of components, understanding how to apply the physics of this rock-breaking method in a commercial product, control and automation, and bringing together an entire mining system.

The machine itself looks something of a hybrid between a roadheader and a drill rig based on a crawler unit. Joy has been working hard to add a new improved boom, and has also been focusing on refining the automation system to suit the equipment and application.

The control system has been lifted from Joy’s underground hybrid LHDs, another ongoing R&D project. The company knows the platform well and the main focus has been on software development for the tunnel-profile-cutting system.
“We are focused on producing one product that is flexible across many applications in tunnel sections from 15m² to 25m². The goal is an extremely versatile system that can be deployed rapidly across many types of mining environments,” Neilson tells MM.

There is currently no official launch date for DynaCut, although MM understands the prototype was on its way to an underground mine in July for testing, presumably Newcrest Mining’s Cadia East gold mine in New South Wales, Australia, which has been previously slated as the first recipient.

In an interview with MM’s managing editor, Richard Roberts, earlier this year, Neilson said that the next underground test-phase would focus not only on instantaneous cutting rates but also ‘process’ advance rates: how consistently fast the system can drive a metre of decline, and of course the cost.

“The second objective is that we fully autonomously cut tunnel profiles within a particular set of parameters that we set,” he said at the time. “The third thing is we need to define the issues with material movement. For example, do we get blocky material? Can we handle the material through the conveyor system? Do we have hang-ups with cut material in particular areas of the profile that [result from] a problem with the cutting system?

“The sub-sets [of these three main test areas] are around the usual stuff you’d expect to see as you drive towards a commercial product. What does the reliability look like? What are the failure points? Have we got the packaging correct around hydraulics, and electrics etc.”

According to Neilson, the company has “a pipeline of concepts based on the cutting technology”, but is for now “focused on providing a single hard-rock continuous mining system that can be deployed across many applications”.

MM understands that this is likely to mean a more selective low-seam miner based on the DynaCut model for narrow-vein applications, which would ultimately give Joy exposure to a broader range of market opportunities in future.

**Roller-disc undercutting**

Sandvik is currently working on a RMDS named the MX650 according to the company’s alpha-numerical product coding.
Sandvik’s MX650 will be a mechanical excavation machine applying roller-disc undercutting technology

“The MX650 will be a mechanical excavation machine applying roller-disc undercutting technology,” says Restner. “The machine will be very smart in terms of size, flexibility, mobility and manoeuvrability. Material loading and conveying as well as rock-support installation will be integral features of the high-capacity rock-excavation system.”

The machine is currently in the manufacturing stage, and Sandvik expects the prototype to be fully assembled and functionally tested by end of the year.
Restner explains that the tricky part of hard-rock cutting is to achieve a high excavation volume per time unit, as only a certain amount of ‘rock disintegration energy’ can be applied in a certain size or scale of excavation.

“Basically, in hard-rock cutting you have to apply a high amount of energy for rock disintegration on a relatively small size of excavation. The full potential of hard-rock cutting is seen by the industry to some extent, but it really will be realised when the first machines are absolutely successful in operation,” he adds.

“We got quite early into roller-disc undercutting and achieved quite reasonable results with this technology. So, of course, it influenced our further R&D work,” Restner tells MM. “But we also kept an eye on other and alternative hard-rock cutting technologies, partly also used by our competitors today. Additionally, we also investigated and explored non-mechanical rock-disintegration technologies, like micro-wave irradiation, for example.”

The MX650 is primarily designed for mine development in excavations from 4x4m to 5x5m. “We target the entire hard-rock mining market, for example: block and panel caving, sub-level caving, narrow-reef mining, narrow-vein mining as well as room-and-pillar mining,” Restner says.

Sandvik expects the MX650 to provide significant benefits for: health and safety; the environment; high excavation speed and reduced time to full production; improved tunnel quality, reducing support and rehabilitation costs; and reduced operating costs through lower manpower requirements.

The company inaugurated a special high-load, hard-rock cutting test rig at its mechanical-cutting competence centre in Zeltweg, Austria, in early 2015.

“At the Zeltweg facility, we just explored and investigated in detail the cutting technology we are now using on the MX650,” says Restner. “Internal prototype testing will take place in the first half of 2017 at Sandvik’s tungsten mine in Austria. So we will have already tested the MX650 in a real underground-mining environment before we bring the machine to the first customer site.”

In terms of R&D, what’s next for the Sandvik?

“The MX650 should be an initiator for an entire hard-rock cutting product line, and we are observing the market for certain needs and different requirements,” says Restner.

“Additionally, we look on supplying the hard-rock mining market with entire mining-system solutions for their applications, and not only and simply supplying them with excavation machines.”

The official market launch for the MX650 is expected in 2018, after successful completion of a customer acceptance test in the second half of 2017.

Steel-disk cutting
Atlas Copco has been committed to the type of steel-disk cutter technology traditionally used on TBMs since the 1980s when the company first started the Atlas Copco Tunnel Boring product line.
“We see the benefit in using a technology that is proven in civil tunnelling, and we see the potential in doing technology development together with TBM suppliers of today,” Ramström says.

Atlas Copco Mobile Miner for Anglo American

The Mobile Miner (Anglo American RMDS) and its sister machines are mainly for mine and tunnel development. However, the system can also be used for mining of ore, for example at a room-and-pillar mine.

“One of the main benefits we see is no need to shut down ore production for blasting and ventilation of gases after blasting,” says Ramström. “A Mobile Miner will mine continuously.”

The Mobile Miner was soon to be deployed underground at Anglo’s Twickenham platinum mine in South Africa when MM spoke to the miner in February. MM presented Donovan Waller, head of innovation at Anglo American, with the 2015 Mining Magazine editor’s award for its pioneering work on the RMDS.

Waller said at the time that following testing at a quarry in Sweden, where it “met all of the performance parameters that we set for it”, a test programme in hard, abrasive rock at Twickenham was set to get under way in March.

“Things are looking good and we’re starting to put the unit into our designs of the future in anticipation of getting good results,” he told MM.

“The unit is going to go down into our Twickenham mine into a test section and it will go through tests for 3-6 months, depending upon what kind of issues we run into. And after that [if all goes well], we will start deploying it into our operations.”
Ramström says that results from the first tests have not been made public yet.

“We have promising results and will make these available at market introduction,” he tells MM. “I can say that the results are so encouraging that we continue our efforts and will soon start yet another project with a customer.

“We are very excited to soon show (prove) to the industry that Rio Tinto and Anglo American did the right thing when investing in this technology.”

When asked about the challenges encountered during development of the Mobile Miner, Ramström cites the conservative nature of the mining industry as key.

“We also see mental barriers when it comes to ground support close to the Mobile Miner. But these have been solved in close co-operation with the mining companies’ rock-mechanics experts,” he adds.

Ramström was unable to disclose details of technologies or features that were investigated during development of the Mobile Miner as “we hope to include these features in future projects”.

“But I can say that we always listen to our customers and move in the direction where our customers go,” he elaborates. “As a consequence, we will see more and more automation and productivity improvements on our Mobile Miner product line, as this is a common request from all customers.”